



# **Overview of RF Exposure Concepts and Requirements**

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**Federal Communications Commission  
Office of Engineering and Technology  
Laboratory Division**



# RF Exposure Requirements

## ● Exposure Standards

- ANSI/IEEE C95.1-1992
- NCRP Report No. 86

## ● FCC Proceedings

- ET Docket 93-62
  - FCC 96-326: Report & Order
  - FCC 96-489: 1<sup>st</sup> MO&O
  - FCC 97-303: 2<sup>nd</sup> MO&O
- ET Docket 03-137
  - FCC 03-132: NPRM



# Rules & Procedures

## ● FCC Rules: 47 CFR

- Licensed & Unlicensed transmitters
  - §1.1307: fixed facilities
  - §2.1091: mobile installations
  - §2.1093: portable operations

## ● FCC documents

- OET Bulletin 65: overall requirements
  - Supplement A: fixed transmitters
  - Supplement B: amateur radio
  - Supplement C: mobile & portable devices
- OET Bulletin 56: consumer FAQ



# Operating Conditions

- Fixed facilities: §1.1307 (MPE)
  - antennas on outdoor permanent structures
    - whole body exposure in far-field conditions
    - broadcast towers, basestations etc.
- Mobile installations: §2.1091 (MPE @  $\geq 20$  cm)
  - antennas on non-permanent objects & structures
    - partial body exposure between near to far field conditions
    - vehicle-mounted antennas, desktop configurations etc.
- Portable operations: §2.1093 (SAR @  $< 20$  cm)
  - devices at close proximity to persons
    - localized exposure in near-field conditions
    - wireless handsets, Wi-Fi products etc.



# Exposure Conditions

- Occupational / Controlled Exposure
  - must be work related or transient in nature
    - person must be fully aware of exposure
    - person must have knowledge to control & limit exposure
    - require RF exposure training
    - higher exposure limits apply
- General Population / Uncontrolled Exposure
  - all other situations
    - apply to all consumer devices
    - no knowledge of exposure required
    - more restrictive exposure limits apply





# Time Averaged Exposure

- Occupational / Controlled exposure conditions
  - any 6-minute duration for both MPE (and SAR)
  - operational based duty factor is acceptable
- General Population / Uncontrolled exposure conditions
  - fixed installations
    - any 30-minute duration with respect to MPE limits
  - mobile and portable operating conditions
    - operational duty factors do not apply
    - source-based time-averaging is acceptable
      - inherent to hardware design or transmission protocol
      - may include certain hardware or firmware restrictions



# MPE

## Occupational/Controlled Exposure Limits

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm <sup>2</sup> )	Averaging Time  E  <sup>2</sup> ,  H  <sup>2</sup> or S (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	(900/f <sup>2</sup> )*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

## General Population/Uncontrolled Exposure Limits

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm <sup>2</sup> )	Averaging Time  E  <sup>2</sup> ,  H  <sup>2</sup> or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	(180/f <sup>2</sup> )*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz

\*Plane-wave equivalent power density



# SAR

## Occupational/Controlled Exposure Limits (W/kg)

Whole-Body	Partial-Body	Hands, Wrists, Feet and Ankles
0.4	8.0	20.0

## General Population/Uncontrolled Exposure Limits (W/kg)

Whole-Body	Partial-Body	Hands, Wrists, Feet and Ankles
0.08	1.6	4.0

*Whole-Body SAR* is averaged over the entire body.

*Partial-body SAR* is averaged over any 1 g of tissue in the shape of a cube.

*SAR for hands, wrists, feet and ankles* is averaged over any 10 g of tissue in the shape of a cube.

SAR limits are not applicable above 6.0 GHz; MPE limits for field strength and power density should be applied. Categorical exclusion of routine MPE evaluation for mobile transmitters does not apply to portable devices operating above 6.0 GHz.





# Routine Evaluation

- Potentials for exposure usually vary with operating configurations & exposure conditions
- Potential for exceeding limits may
  - require routine evaluation to demonstrate compliance
  - allow certain operations to be categorically excluded from routine evaluation
- Routine evaluation is required according to
  - Table 1 of §1.1307 for fixed facilities
  - §2.1091(c) for mobile operations
  - §2.1093(c) for portable devices
- Evaluation may be triggered by §1.1307(c) or (d)



# RF Exposure Labels

- Labels must be legible and clearly visible for the exposed persons to meet exposure requirements
- Labels may be used to identify RF exposure training material for satisfying occupational use conditions
- For general population exposure conditions
  - labels generally do not substitute for routine evaluation
  - device should demonstrate compliance for normal operations without use of labels
  - labels may apply to certain unintended and mostly intermittent conditions of increased potential for exposure
  - operating instructions and caution statements should be included in manuals to alert users about proper operation



# Fixed Transmitter Sites

- Fixed transmitters operate at different frequencies may be collocated on towers and buildings etc.
  - exposure depends on the antenna configuration at a site
  - compliance is usually determined at the time of licensing according to §1.1307(b)(3)
- RF exposure labels are required for subscriber transceivers - BRS, EBS, LMDS AND DEMS
- Compliance for both general population and occupational limits are required
- Unlicensed PCS and NII devices must use general population limits; occupational limits do not apply



# Mobile Operations

- Mobile configurations require antennas & radiating structures to operate at  $\geq 20$  cm from persons during normal use
- Routine evaluation is required according to §2.1091
  - $> 1.5$  W ERP @  $< 1.5$  GHz and  $> 3.0$  W ERP @  $\geq 1.5$  GHz
- Evaluation may include
  - field strength and/or power density measurements
  - computational modeling
  - estimations based on certain simple & generic exposure conditions
- Different time averaging requirements apply for general population and occupational exposure conditions
- Additional considerations are required for collocated transmitters that may transmit simultaneously






# Typical Mobile Configurations

- Vehicle-mounted antennas
  - occupational vs. general population exposure conditions
  - work-related operator vs. passengers & nearby persons
- Independent and embedded consumer devices
  - typical desktop and similar devices
  - desktop and laptop (display only) computer configurations
  - compliance requires proper installation
- Marine radios operating on various size vessels
  - small boats vs. large ocean liners
  - mobile vs. fixed configurations





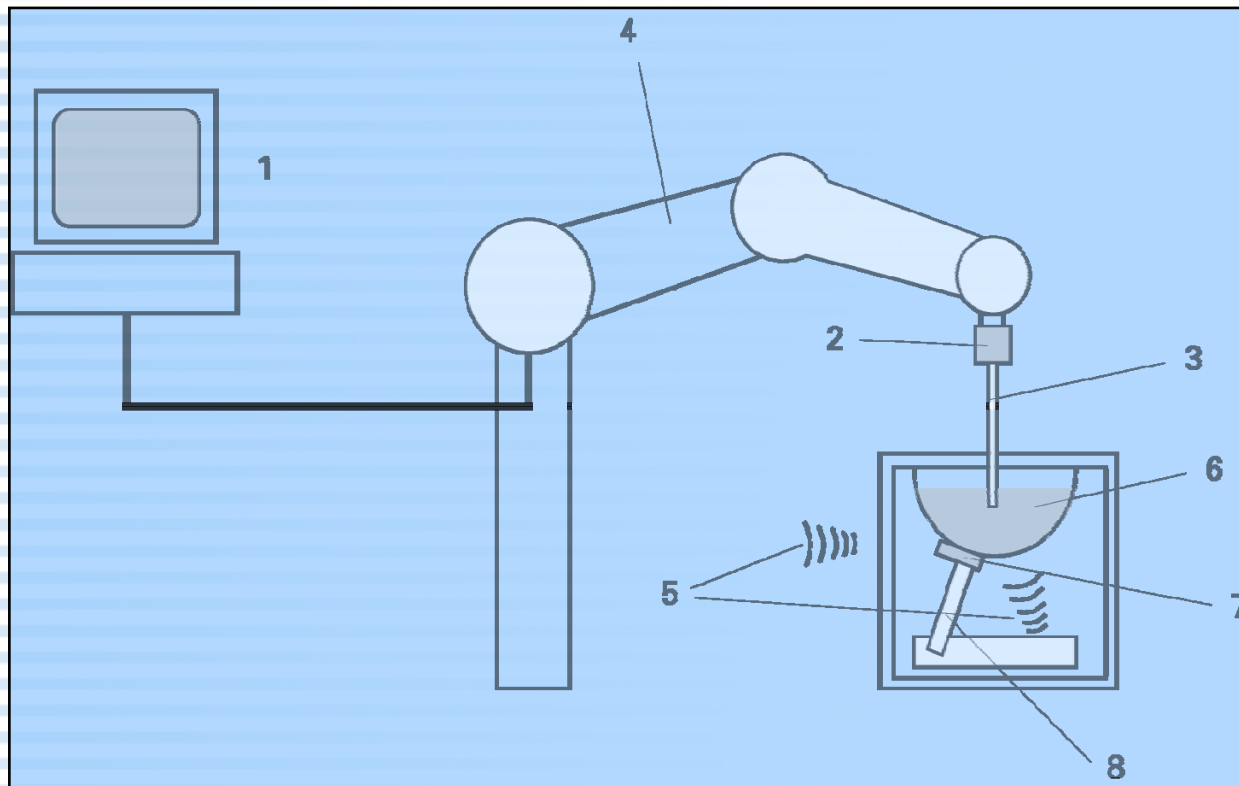
# Collocated Mobile Devices

- Independent without simultaneous transmission
  - Simultaneous or overlapping transmissions
    - at single or multiple frequencies
    - from single or multiple antennas at close proximity
  - Determine compliance according to §1.1307(b)(3)
    - apply frequency dependent MPE limits and compute the sum of MPE ratios (MPE/MPE limit at each frequency)
    - include applicable source-based time-averaging
    - determine minimum separation boundary ( $\geq 20$  cm)
-  according to output power and spatial separations among antennas

Example Multiple Tx  
MPE Spreadsheet



# SAR Measurement Overview



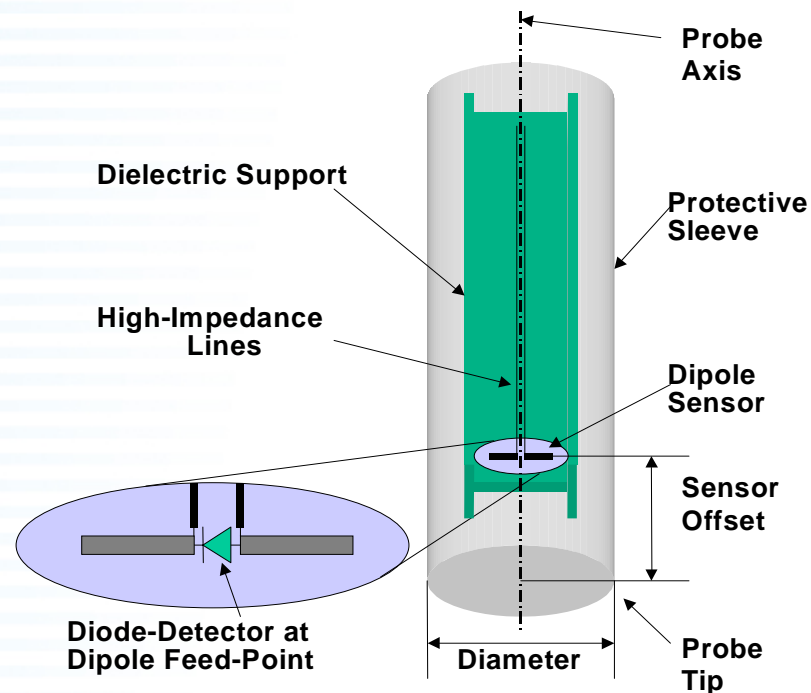
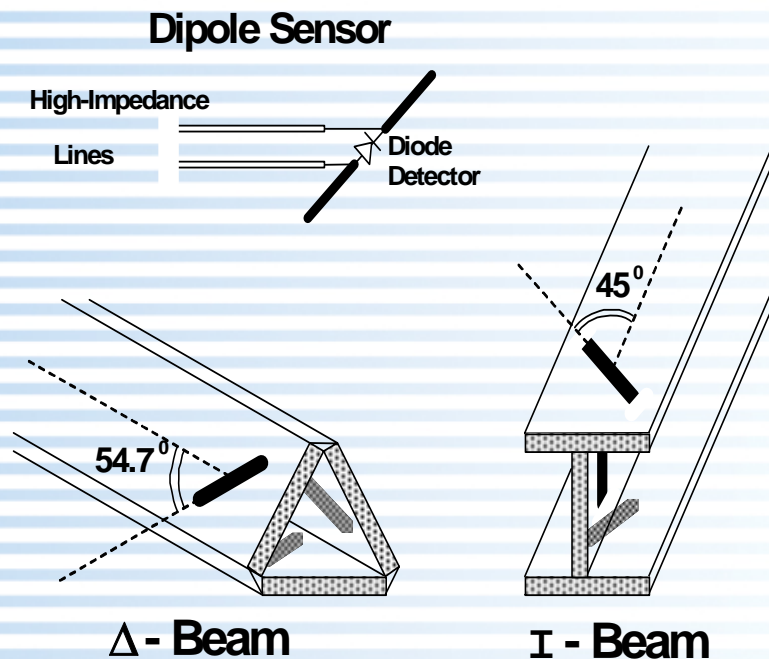
- 1) computer for data recording
- 2) data acquisition unit
- 3) dosimetric E-field probe
- 4) probe positioner
- 5) ambient field
- 6) phantom shell with tissue simulating liquid
- 7) device under test
- 8) device positioner



# Field Probe Construction

- Miniature E-field probes with 3 orthogonal dipole sensors operating with diode detectors for evaluating the SAR of low power devices

- $|E| = (|E_1|^2 + |E_2|^2 + |E_3|^2)^{1/2} = (v_1/\gamma_1 + v_2/\gamma_2 + v_3/\gamma_3)^{1/2}$





# Field Probe Calibration

- $SAR = \sigma|E|^2/\rho = c\Delta T/\Delta t$
- Frequency and tissue dielectric property dependent
- Calibration point is at geometric center of sensors
  - sensors are not at probe tip and are offset from probe axis
- Probe calibration procedures for 0.3-3 GHz are described in IEEE Standard 1528
- Probes should be calibrated in gradient fields using
  - temperature rise technique -  $< 800$  MHz
  - waveguide technique -  $\geq 800$  MHz



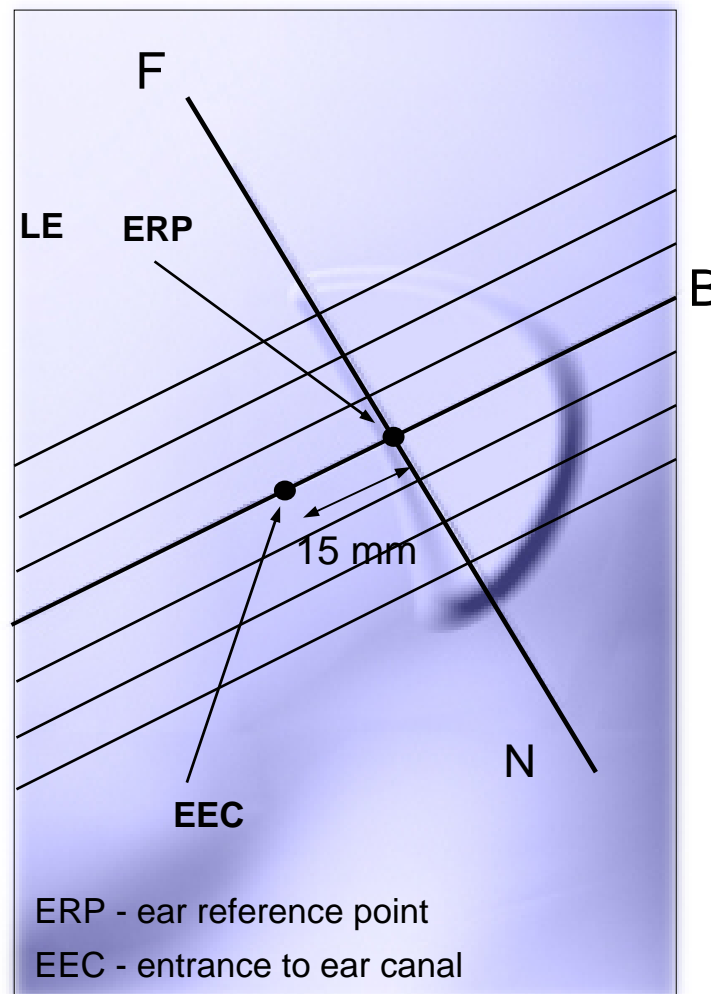
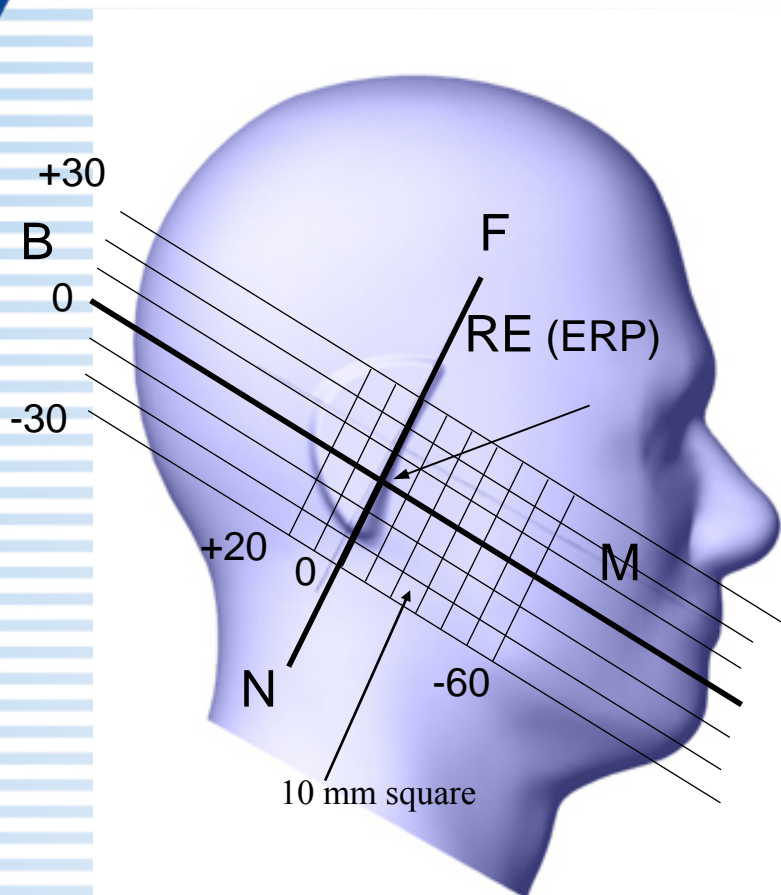
# Phantom Requirements

- IEEE Standard 1528 SAM head phantom for testing handsets next to the ear
- Flat phantom for system validation and testing other operating configurations
- Phantom shell dielectric properties, shape and dimensions are fully defined in Standard 1528
- Homogeneous tissue-equivalent liquids are used
- Tissue dielectric parameters are defined
- Currently no hand phantom available





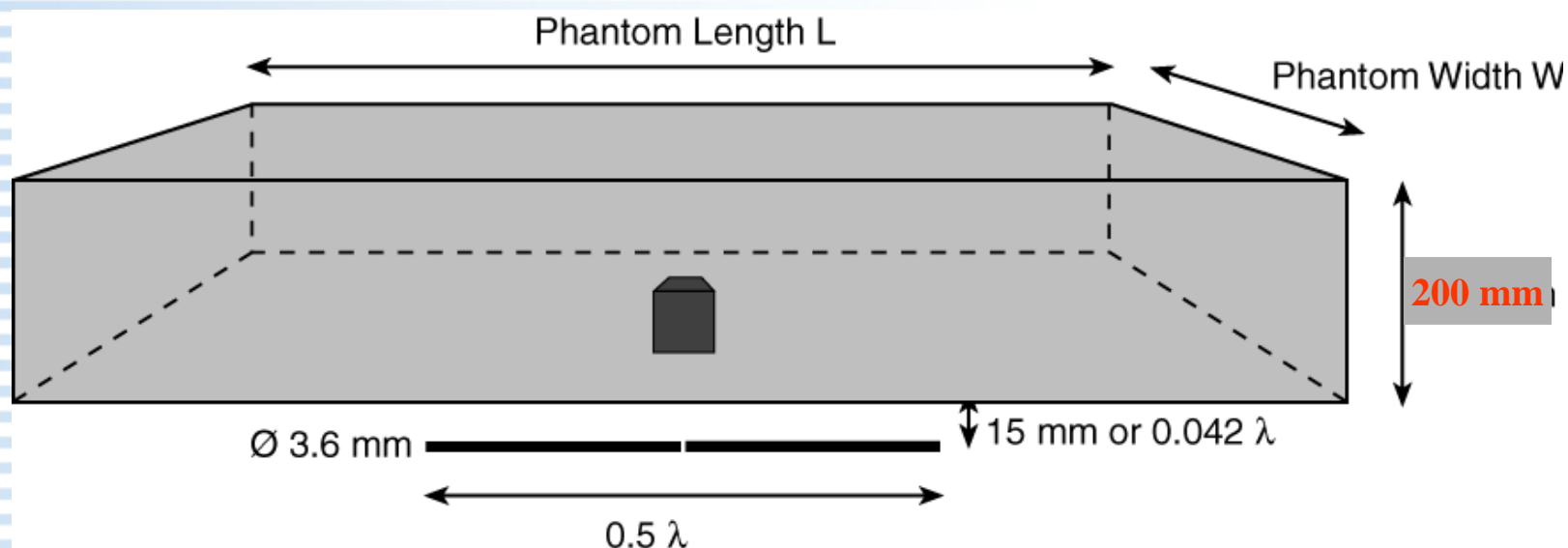
# SAM Phantom Definitions





# Flat Phantom Definitions

- shell thickness
  - bottom:
    - $> 800$  MHz -  $2.0 \pm 0.2$  mm with  $< 1\%$  sagging (of  $\lambda_{\text{air}}$ )
    - $\leq 800$  MHz -  $< 6.5 \pm 0.2$  mm with  $< 0.5\%$  sagging (of  $\lambda_{\text{air}}$ )
  - other regions: unspecified
- length and width:  $\geq 0.6 \lambda$
- liquid depth:  $15.0 \pm 0.5$  cm
- shell material:  $\epsilon_r < 5.0$  and loss tangent  $< 0.05$





# Tissue Dielectric Properties

Target Frequency (MHz)	Head		Body	
	$\epsilon_r$	$\sigma$ (S/m)	$\epsilon_r$	$\sigma$ (S/m)
150	52.3	0.76	61.9	0.80
300	45.3	0.87	58.2	0.92
450	43.5	0.87	56.7	0.94
835	41.5	0.90	55.2	0.97
900	41.5	0.97	55.0	1.05
915	41.5	0.98	55.0	1.06
1450	40.5	1.20	54.0	1.30
1610	40.3	1.29	53.8	1.40
1800 – 2000	40.0	1.40	53.3	1.52
2450	39.2	1.80	52.7	1.95
3000	38.5	2.40	52.0	2.73
5800	35.3	5.27	48.2	6.00

( $\epsilon_r$  = relative permittivity,  $\sigma$  = conductivity and  $\rho = 1000 \text{ kg/m}^3$ )



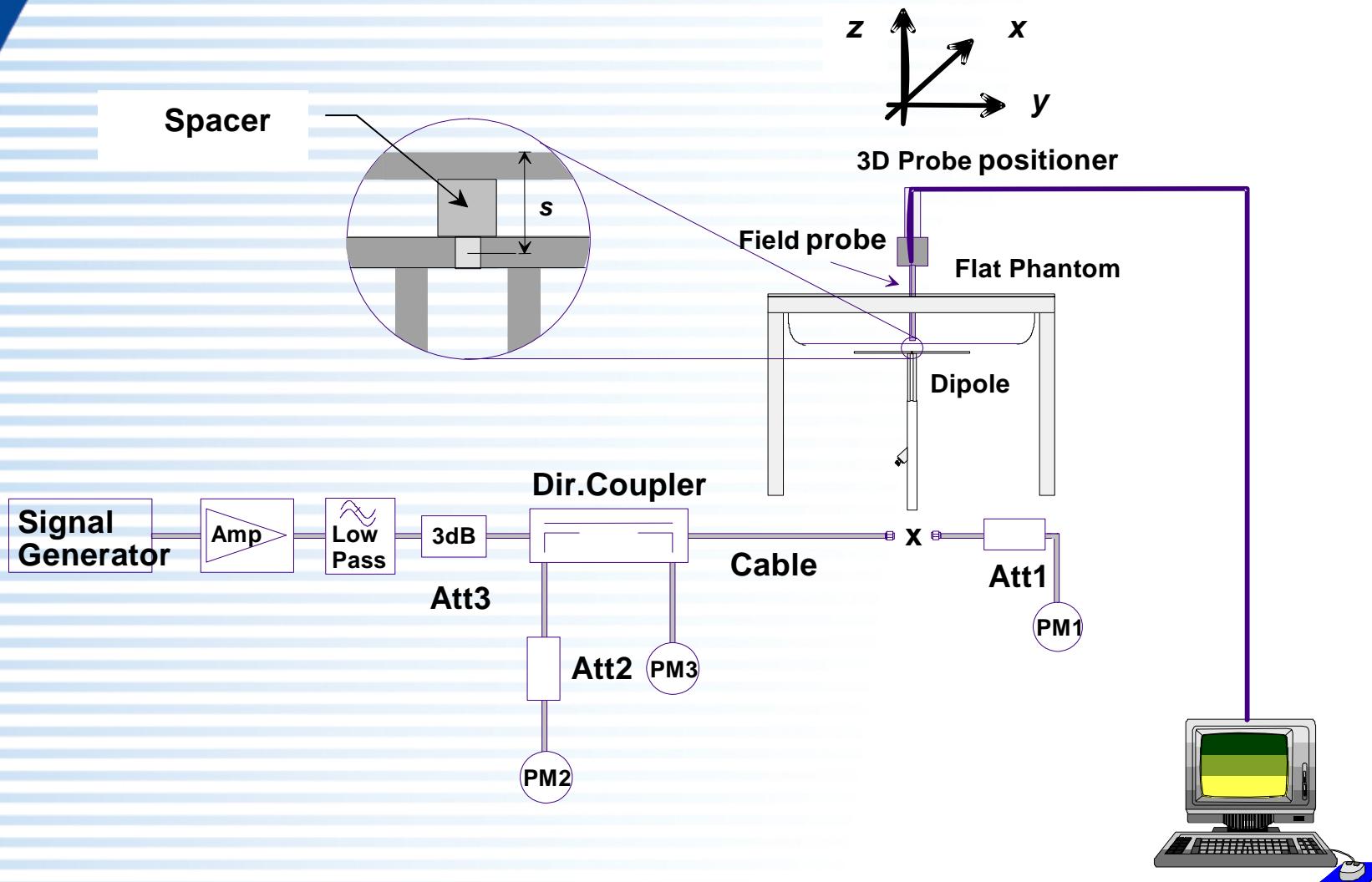
# Tissue Property Measurements

- IEEE 1528 recommended procedures
  - liquid filled Coaxial slotted line
  - Coaxial probe in liquid
  - liquid filled TEM-Line
- Sensors are connected to network analyzer
- dielectric constant and conductivity are calculated from reflection coefficients
- measuring standard liquids to verify accuracy
- 5% measurement uncertainty required



# SAR System Verification

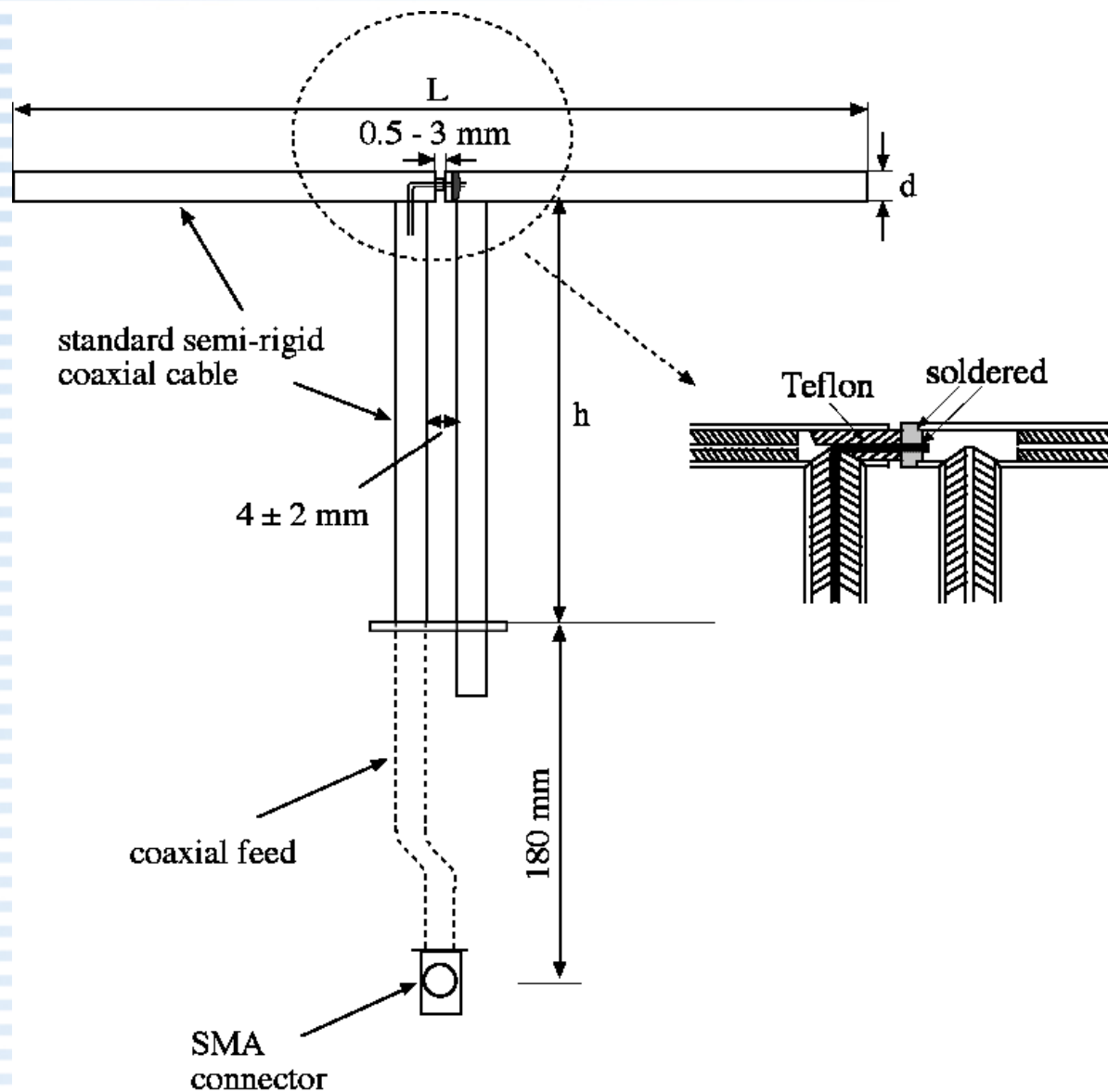
Measured SAR within  $\pm 10\%$  of target values







# Reference Dipoles





# Dipole Reference SAR Values

Frequency (MHz)	1 g SAR	10 g SAR	local SAR at surface (above feedpoint)	local SAR at surface (y=2cm offset from feedpoint)
300	3.0	2.0	4.4	2.1
450	4.9	3.3	7.2	3.2
835	9.5	6.2	14.1	4.9
900	10.8	6.9	16.4	5.4
1450	29.0	16.0	50.2	6.5
1800	38.1	19.8	69.5	6.8
1900	39.7	20.5	72.1	6.6
2000	41.1	21.1	74.6	6.5
2450	52.4	24.0	104.2	7.7
3000	63.8	25.7	140.2	9.5



# Typical Test Configurations

- SAR is typically tested on high, middle & low channels
- Handsets are usually tested
  - on the left and right side of the SAM phantom
  - in cheek touching and 15° tilt positions
  - with antenna extended and retracted, as appropriate
  - tests are repeated for all operating modes and frequency bands with certain exceptions
- Other configurations are generally tested on high, middle & low channels with the device positioned at a appropriate distance from a flat phantom



# SAR Scan Procedures

- Area scan to determine peak SAR locations
  - peak SAR mostly near surface of homogeneous phantoms
  - probe boundary effects error requires probe tip location
    - $> \frac{1}{2}$  probe diameter distance from phantom surface
  - typical scan resolution
    - 1-2 cm at  $< 3$  GHz and  $\leq 1$  cm at  $> 3$  GHz
    - measured values are interpolated to identify peak locations
- zoom scan to determine volume averaged SAR
  - typical scan configurations
    - 5 x 5 x 7 points in 3 x 3 x 3 cm<sup>3</sup> volume at  $< 3$  GHz
    - 7 x 7 x 7 or more points at 3-6 GHz
  - 1-g SAR is computed by
    - extrapolating measured values to the phantom surface
    - interpolating and then integrating with respect to a 1 cm<sup>3</sup>



# SAR Measurement Uncertainty

- Identifies the probability of a measured value from its true value
- Standard uncertainty of an uncertainty component
  - type A - statistical analysis of a series of observations
    - estimating the standard deviation
  - type B - other than statistical analysis
    - based on scientific judgement - reference data and specifications
- Combined standard uncertainty
  - estimate the standard deviation by combining standard uncertainties using the “root-sum-squares” method
- Expanded uncertainty
  - multiplied the combined uncertainty by a coverage factor
  - defines the probability of the measured result in an interval where the true value is believed to be

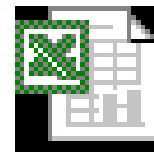




# Reporting Uncertainty



IEEE 1528 Uc



Uc Spreadsheet  
Template

**For Information only**



# Simultaneous Transmission

- SAR measurements are frequency dependent due to
  - probe calibration requirements
  - tissue dielectric parameters
- Simultaneous transmission at multiple frequencies requires SAR to be evaluated independently for each frequency using appropriate probe calibration and tissue dielectric parameters in identical device positioning conditions; i.e. measurement registration
- The results can be summed grid by grid according to the same measurement scan setup, followed by interpolation and extrapolation to compute 1-g SAR



# TCB Exclusion List



TCB Exclusion List

**For Information only,  
details are discussed separately**



# TCB RF Exposure Qualification

- TCB training on SAR and general RF exposure procedures required to qualify for RF exposure scope
- Training material may include:
  - information and videos available for previous trainings
  - Supplement C, IEEE Standard 1528 and other related standards
  - summary and updates provided in current workshop
  - all other necessary updates on FCC rules, administrative policies and equipment certification procedures available from the FCC (knowledge database) and through the TCB council
- Attend additional trainings in future workshops on updates and new procedures to maintain qualification



# Other Considerations

- Modular approval of unlicensed transmitters
  - see Public Notice DA 00-1407
- 3-6 GHz SAR requirements - pending
- Digital technology – Wi-Fi, Wi-Max, 3-G protocols
- Permissive Change requirements: Class I, II, III
- Applying meaningful and acceptable grant comments and conditions
- Pending proceedings – ET Docket 03-137
  - fixed transmitters
  - mobile and portable modules (§§ 15.247 and 15.407)